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ABSTRACT

Prediction of fatigue life on cylinder head for two stroke engine using constant and variable amplitude loading are presented. The objectives of this project are to predict fatigue life of cylinder head for two stroke internal combustion engine, to identify the critical location, to investigate the effect of mean stress of stress life and strain life method, to optimize the component material and to compare both constant and variable amplitude loading results. The structural and finite element modelling has been performed using a computer aided design and finite element analysis software package. The finite element model of component then analyzed using the linear elastic approach. Finally, the stress-strain state of component obtained previously will employ as input for the fatigue life. The effect of mean stress and materials optimize will be investigated. The cylinder head is the crucial part of the internal combustion engine. The failure of cylinder head can result in devastating damage to the engine including all the components from a tiny screw till a huge engine block. Life of cylinder head needs to be improved to prevent from any unpleasant problems. The result of the analysis was showed that there are no serious failure occurs at the part of the cylinder head and however it is observed that the minimum predicted life at the critical location is $10^{2.38e-7}$ under constant amplitude loading and variable amplitude loading for stress life approach and the predicted life for strain life approach is $10^{2.62}$ and $10^{2.14}$ each under constant and variable amplitude loading. The optimization results were showed that 7075-T6 is the most superior material among the others.

ABSTRAK

Ramalan jangka hayat lesu bagi kepala silinder enjin linear dua lejang dipersembahkan. Objektif projek ini dijalankan adalah termasuk untuk meramal jangka hayat lesu bagi kepala silinder enjin linear dua lejang, untuk mengenalpasti lokasi kritikal yang terdapat pada kepala silinder, untuk menyiasat kesan tindakan purata keterikan jangka hayat keterikan dan purata keterikan jangka hayat ketegasan, untuk mengoptimumkan pemilihan bahan komponen dan membuat perbandingan keputusan antara daya amplitud malar dan daya amplitud bervariasi. Struktur model dan model elemen finiti telah dibuat menggunakan perisian lukisan secara berkomputer dan pakej perisian analisis elemen finiti. Model bagi elemen finiti tersebut kemudian dianalisa menggunakan pendekatan linear elastik. Akhir sekali, keterikan dan ketegasan yang telah didapati bagi komponen tersebut akan digunakan sebagai input untuk jangka hayat lesu. Kesan purata keterikan dan pemilihan bahan secara optimum akan diselidik. Kepala silinder merupakan komponen penting di dalam sistem enjin pembakaran dalam. Sebarang kegagalan pada kepala silinder akan menyebabkan kerosakan yang teruk pada enjin daripada sekecil skru hingga sebesar blok enjin. Jangka hayat bagi kepala silinder perlu diperbaiki untuk mencegah daripada sebarang masalah yang tidak diingini. Keputusan analisis menunjukkan tidak terdapat kegagalan yang serius pada bahagian kepala silinder walau bagaimanapun, didapati bahawa jangka hayat minimum yang diramal pada lokasi yang kritikal ialah $10^{2.38e-7}$ dibawah tindakan amplitud malar dan amplitud bervariasi untuk jangka hayat keterikan dan jangka hayat minimum yang diramal untuk jangka hayat ketegasan pula ialah $10^{2.62}$ dan $10^{2.14}$ setiap satu dibawah tindakan amplitud malar dan amplitud bervariasi. Keputusan analisis pemilihan bahan secara optimum mendapati bahawa bahan 7075-T6 pula ialah bahan yang didapati terbaik berbanding bahan-bahan lain yang dikaji di dalam analisis.

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LIST OF SYMBOLS

σ_a	Stress amplitude
σ'_f	Fatigue strength coefficient
$2N_f$	Reversal to failure
N_f	Fatigue life
S_e	Alternating stress
σ_m	Mean stress
S_u	Ultimate tensile strength
$\Delta \epsilon / 2$	Total strain amplitude
E	Modulus of elasticity
σ_{max}	Maximum stress
σ_{min}	Minimum stress
R	Stress ratio
G	Shear modulus
b	Fatigue strength exponent
c	Fatigue ductility exponent

ε'_f	Fatigue ductility coefficient
S_f	Fatigue strength
K'	Cyclic strength coefficient
n'	Cyclic strain hardening exponent
SRII	Stress range intercept
NC1	Transition life
SE	Standard error

LIST OF ABBREVIATIONS

CAL	Constant Amplitude Loading
VAL	Variable Amplitude Loading
FEM	Finite Element Modeling
mm	Milimeter
Mpa	Mega Pascal

CHAPTER 1

INTRODUCTION

1.1 Background

1.1.1 Cylinder head

Cylinder head in general is a compartment which seals the cylinder block on top and provides the portion which the combustion can take place. The most common application of cylinder head is in an automobile engine. However, there are many applications of cylinder head in other application of any stroke engine from small one cylinder to very large multi cylinder engine.

In an internal combustion engine, the cylinder head sits a top of the cylinders and consists of a platform containing part of the combustion chamber and the location of the valves and spark plugs. Cylinder head is a vital compartment in an automotive engine as it is a function of the engine configuration. A straight engine has only one cylinder head. The cylinder head is a key to the performance of the internal combustion engine.

The primary difference between the two-stroke engine cylinder head and the four-stroke engine cylinder head is that there are no ports (and therefore no valves) in the two-stroke cylinder head. This makes the two-stroke cylinder head much simpler to produce. The main purpose of the two-stroke cylinder head is to create a combustion chamber by sealing the area between the cylinder and the cylinder head. Furthermore, it is functioning to hold the spark plug. A squish area (best describe as narrow edge meet between cylinder head and cylinder wall - for simple cylinder head without fin) of the combustion chamber forces the air-and-fuel mixture into a tight pocket under the spark plug to increase the combustion efficiency. The squish area,

or as it's also known, squish band, is more critical in the two-stroke engine as compared to the four-stroke engine. The modern two-stroke cylinder head is constructed of aluminum alloy. In other dimension, like four-stroke cylinder heads, two-stroke cylinder heads also aid in the transfer of heat from the engine by the use of fins on air cooled engines or water jackets on liquid-cooled engines.

There are several different material options available for manufacturing two stroke engine cylinder head, with the popular categories; cast-iron cylinders have a one-piece design. The cast-iron cylinder is inexpensive to manufacture but has poor heat transfer characteristics when compared to other materials used to construct cylinders. Cast-iron cylinders are also very heavy. Besides, aluminum cylinders with cast-iron or steel sleeves have much better heat transfer abilities than cast-iron cylinders and are much lighter in weight. Other, plated-aluminum cylinders, which are also called Nikasil or composite cylinders, have the best heat transfer characteristics of any produced today. They are the lightest-weight cylinder available and, when properly maintained, are the longest lasting cylinders. These cylinders are expensive to replace when compared to the other types of cylinders.

Cylinder head of two stroke engine design in modern production is mostly produced from aluminum alloy as mentioned previous for better maintenance. Fatigue analysis also plays a major role in performance of cylinder head of the internal combustion engine. Most of previous studies Glancey and Stephens (2005) related to variable amplitude loading of aluminum alloy to predict the lifetime. For this similar material, fatigue crack initiation (strain life) is required to achieve better result. However the previous study Miyazaki et al. (2007) indicated only on that prediction on high cycle fatigue life while Glancey and Stephens (2005) exhibited that better variable amplitude on fatigue crack growth resistance but in this paper the prediction is continued on stress life and strain life approach for the new cylinder head of two stroke engine.

1.1.2 Fatigue

Fatigue is the process of cumulative damage in a benign environment that is caused by repeated fluctuating load and, in the presence of an aggressive

environment, is known as corrosion fatigue. Fatigue damage of components subjected to normally elastic stress fluctuation occurs at regions of stress (strain) raisers where the localized stress exceeds the yield stress of the material. After a certain number of load fluctuations the accumulated damage causes the initiation and subsequent propagation of a crack or crack in the plastically damaged regions. This process can and in many cases does cause the fracture of components. The more stern the stress concentration, the shorter the time to initiate a fatigue crack.

Structural components are subjected to a variety of load (stress) histories. The simplest of these histories is the constant-amplitude loading. This type of loading usually occurs in machinery parts such as shafts and rods during periods of steady-state rotation. The most complex fluctuating-load history is variable amplitude loading. This type of loading is experienced by many structures including offshore drilling rigs, ships, aircraft, bridges, and earthmoving equipment.

Fatigue causes failure when structures subjected to fluctuating service loads in sufficient numbers. Although the number of structures that have failed due to fatigue is less and the consequences can be costly in term of property damage and human life, the consequences may be extremely bad especially when lacking of appropriate inspection intervals are observed and fatigue damage can grow and accumulate during service life.

1.2 Problem Statement

The cylinder head is the vital part on top of the internal combustion engine and its failure would render the engine useless and the system is out of function until costly repairs or replacement of the new one could be installed. The failure of cylinder head can result in catastrophic damage to engine. In some cases cylinder head cracking may result in such severe injury to the engine that is must be replaced. The minor crack will lead to lose compression and misfire while major cracks cause severe damage to cylinder head engine. Life of cylinder head needs to be improved to be better. Several researchers have proposed methods for estimating the fatigue strength from a propagation life of a fatigue crack. In this study, a method for predicting fatigue life of a cylinder head with the same material only concern on

stress life approach and strain life approach under constant amplitude and variable amplitude are proposed.

1.3 Scope of the Project

This project is concerned on structural modeling, finite element modeling (FEM), fatigue analysis and optimization of material.

1.4 Objectives of the Project

The objectives of this project are:

- i. To predict fatigue life of cylinder head for two stroke internal combustion engine and to identify the critical location.
- ii. To investigate the effect of mean stress of stress life and strain life method and optimize the component material.
- iii. To compare both constant and variable amplitude loading results.

1.5 Significance of the Project

This paper is carried out the study of fatigue life using constant and variable amplitude loading of automotive component. The focus of this study is to improve the life of an automotive component such as cylinder head and to achieve successful improvement and efficiency optimized engine.

1.6 Overview of the Project

In the introduction, a description of cylinder head and fatigue are presented. Furthermore the problem statement also is included to determine the source of the problem and to prevent the failure to occur. Besides that, the scope of the project and the objective of the project are also play an important role to emphasize the entire report. The objectives of the project need to be reached to ensure that the analysis can be done successively. Beyond of that, significance of the project shows the relation of the project outcome to the real life.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review for this paper related to the fatigue life analysis, constant and variable amplitude loading that were done previously. Therefore the literature review included in this chapter only contains additional information that was published after the previous literature review was completed and information that is mentioned again due to specific application to this study.

The analysis of fatigue in cylinder head is vital aspect to improve the material including estimating life. In this report, as it allows the researcher to better adapt experiments to real life situations as well as validates results. Cylinder head studies, suggest that cylinder head need to be improved in term of life, which is also supported by the analysis of fatigue and common material used.

2.2 Loading Histories

Glancey and Stephens (2005) investigated comparison between variable amplitude loading for a cast and wrought aluminum alloy. In the studies the analysis was performed on cast aluminum alloy, D357, and the wrought aluminum alloy, 2024 and the variable amplitude loading however is applied in the form of single tensile overloads, repeated tensile overloads, and simulated flight spectra loading. The study entirely however indicates that D357 exhibited better variable amplitude fatigue crack growth resistance compared to 2024 under most of the loading conditions.

Rahman et al. (2007) performed the analysis of the fatigue life. The fatigue life is predicted using variable amplitude SAESUS loading histories and condition. The predicted fatigue life results of the cylinder block corresponding to 99% reliability value. In this analysis, the critical locations identified and it is found that the bolt-hole is the most critical positions for the cylinder block.

Dabayeh et al. (1999) conducted fatigue test of cast aluminum alloys under constant and variable-amplitude loading. Three cast aluminum materials, Al 206, Al 319 and Al 390, were used. The constant-amplitude testing included the uses of stress ratio of -1 while the variable-amplitude load history consisted of underloads followed by constant-amplitude small cycles. It is found that underloads reduced the fatigue strength of the alloys by 66–77%. Fatigue life predictions exhibited match result so did with experimental results.

Zheng et al. (1999) studied on fatigue crack initiation life and predicted life of aluminum notched elements under variable amplitude loading. In this study, the corrosion fatigue tests are carried out under both constant and variable amplitude loading to investigate the overload effect on the corrosion fatigue crack initiation (CFCI) life and predict life of LY12CZ aluminum alloy sheets. The predicted CFCI lives of LY12CZ alloy notched elements under VAL agree well with test results. Based on test results and analysis, it may be thought that Miner's rule can be used to predict the CFCI life of notched elements of metals with continuous strain hardening characteristics if the overload effect on CFCI life is taken into account in life prediction under variable amplitude loading.

Zheng et al. (2005) studied about fatigue formula for predicting the expressions of fatigue life of 45 steel notched elements from tensile properties. Both the predicted fatigue lives and the test results of 45 steel notched elements under variable amplitude loading follow the log-normal distribution. The predicted fatigue life of 45 steel notched elements with 50% survivability agrees well with the test results. However, the standard deviation of the predicted fatigue life of 45 steel notched elements under variable amplitude loading is a little higher than that of test results. The studied entirely proposed to reduce the dispersion of fatigue test results

and improve the prediction accuracy of the fatigue life under both constant and variable amplitude loading.

2.3 Fatigue Life

2.3.1 Stress life approach and strain life approach

Lim et al. (2005) predicted the fatigue crack initiation by applying the local stress-strain approaches to for the cyclically non-stabilized and non-Masing steel. The assumption has been made that is material element at the highest stressed zone is simulated by the behavior of the bulk material to predict fatigue crack initiation life. In this study, the following three factors such as material characterization of the bulk material, the calculation of the local stress and strain at notches and the appropriate selection of the damage parameter for the material are essential to predict of fatigue crack initiation. Furthermore, in this study the Neuber's rule and Glinka's ESED method were modified for incremental application. The numerical verifications of the proposed local approximations were accomplished by comparing them with the FEM results.

Raman et al. (2002) discussed on cyclic stress-strain behaviour and low cycle fatigue life. In the study the Coffin Manson and Basquin relations are considered to be in conjunction with the cyclic stress-strain curve for low cycle fatigue of metallic materials. From the analysis it is found that Morrow's and Tomkin's relations connecting the strain hardening exponent n' with the exponents C and b but however in Coffin Manson's and Basquin's equations are not valid. The exponents C and b are not independently related to n' . The exponents C and b are related to the strain hardening exponent n' as $n'=b/C$.

Lee et al. (2005) conducted estimation methods for strain-life fatigue properties from hardness. The (direct) hardness method proposed by Roessle and Fatemi provides excellent estimation results for steels. So-called indirect hardness methods utilizing the ultimate tensile strength predicted from hardness were proposed in this study and successfully applied to estimate fatigue properties for

aluminum alloys and titanium alloys. Based on the results obtained, some guidelines are provided for estimating fatigue properties from simple tensile data or hardness.

Visvanatha et al. (2000) studied influence of strain estimation methods on life predictions using the local strain approach. Life predictions were made using the local strain method for two aluminium coupons (7050-T7451). In the study Neuber's rule overestimates the strain from the FE analysis, while Glinka's method underestimates the FE strain. The Hoffmann and Seeger modification to Neuber's rule improves the estimate for sharp notches. Comparisons of life predictions for 7050-T7451 aluminum under two different spectra show that the strain estimation technique has little influence on the predictions in comparison with the scatter in the experimental results. The use of the simple Neuber approximation for these life prediction methods is therefore acceptable.

2.3.2 Life prediction of aluminum 2024-T3

Gruenberg et al. (2003)^a conducted a fatigue test of pre-corroded 2024-T3 aluminum. A lot study has examined the possibility of total fatigue life prediction methodologies based on the initial condition of the material. In this study, fatigue specimens of nominal gage 0.063 in. aluminum alloy 2024-T3 were exposed to corrosion and tested in a laboratory setting. In general, fatigue tests showed a decrease in life due to increased corrosion exposure. However, the fatigue tests from different specimen orientations exhibited similar lives to failure. The spread from shortest to longest fatigue lives among the different corrosion conditions decreased at the higher stress levels. Life predictions based on measured nucleation sites were generally conservative in nature and within 20–30% of the experimental lives.

Gruenberg et al. (2003)^b conducted fatigue test of pre-corroded 2024-T3 aluminum from breaking load tests. In this study, breaking load specimens of a single nominal gage (0.063") of 2024-T3 alloy aluminum from three different manufacturing lots were exposed to three levels of corrosion. Correlations between breaking load results and fatigue life results in the presence of corrosion damage were developed using a fracture mechanics foundation and the observed mechanisms of failure, through the use of effective flaw size conversions. Life predictions using

this technique, which is based on breaking load data, were generally shorter than the experimental lives by an average of 20%. The life prediction methodology developed from this investigation is a very valuable tool for assessing material substitution for aircraft designers, alloy differentiation for manufacturers, or inspection intervals and aircraft retirement schedules for aircraft in service.

Halliday et al. (2003) predicted fatigue life from long crack data in 2024 aluminium alloy. Confidence bounds are obtained for the small crack growth rate data. A pragmatic approach is adopted to extend the analysis so that fatigue life prediction can be made from long crack growth data. Comparisons are made between fatigue lives reported in the literature for plane and notched samples and predictions obtained using the present analyses. Reasonably good agreement is obtained for both the shortest fatigue lives and for the spreads in fatigue lives. In addition, comparisons of experimental fatigue life data for plane and notched samples of the same alloy obtained from the literature were made with the predictions of the pragmatic long crack approach. Reasonably good agreement was found for both the shortest fatigue life and for the spread in fatigue life and encourages further development of the procedure.

2.4 Computational Analysis

Rahman et al. (2007) investigated the critical location of two stroke free piston linear engine component. The linear static finite element analysis was performed on geometric model of the cylinder block including several contact areas such as cylinder head, gasket and hole for bolt. The analysis was performed using Msc. NASTRAN[®] finite element software. The maximum principal stresses and strains are used to proceed to the fatigue life analysis and comparison. The maximum principal stress of 23.4 MPa occurring at node 92190 was obtained. The predicted fatigue life of the AA6061-T6-80HF aluminum alloy at most critical location near the bolt-hole edge can be obtained using the Coffin-Manson method. It is observed to be $10^{3.44}$ seconds at (node 92190)

Everett (1998) studied the effects of load sequencing on the fatigue life of 2024-T3 aluminum alloy. This type of analysis assumes that there is no load

sequence effect that occurs during the fatigue loading history. Following tests were done on open hole test specimens made of 2024-T3 aluminum alloy on the normal sequence of loads as well as the reordered scheme called lo–hi. Test results however showed no significant differences between the fatigue lives of the normal load sequence and the reordered load sequence. A computer program called FASTRAN[®] was used in the analysis to calculate total fatigue life using only crack growth data and predict the fatigue life of the spectrum tests with acceptable accuracy.

2.5 Conclusion

Stress life and strain life have been used by the researchers but somehow in different way and method to predict fatigue life of the component. In common knowledge, fatigue life can be predicted using stress life approach, strain life approach, and fatigue crack growth approach. Most of the researches that have been done before utilized and preferred crack growth in predicting fatigue life but there are still literature reviews that have similar method compare to this study in prediction of fatigue life which applied stress life and strain life. In addition, types of loading consist of constant amplitude loading and variable amplitude loading. Type of variable amplitude loading used in this analysis is positive loading.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this methodology, a detail description on the work progress and flows are presented. The analysis also included in this chapter and consists of finite element modeling and fatigue analysis.

3.2 Finite Element based Fatigue Life Prediction

Figure 3.1 shows the methodology that began with computational process modeling the structure of the cylinder head. The original cylinder head was modeled using SOLIDWORKS® and the structure then was imported to PATRAN®. The process then continued to finite element modeling. Appropriate mesh was selected for the structure to be modeled and the process was finalized with finite element analysis where all the boundary conditions and loads were included in this first stage analysis. The second process of the analysis was continued simultaneously with fatigue analysis. The analysis was done in NASTRAN® where the cyclic material properties and component load histories were considered. Fatigue life of the component was computed and yield contour of stresses and life cycle where the life prediction had just been made. The critical location can be identified through the observation of contour plotted. Fatigue life was examined and checked at the critical location whether the life was in good prediction condition or it was totally broken. The critical location predicted life emphasizes the prediction life of the entire component. The optimization will be made if the fatigue life was not in good expectation. Thus, certain parameters in the analysis need to be set to improve the fatigue life such scaling factor, mean stress correction method and material.

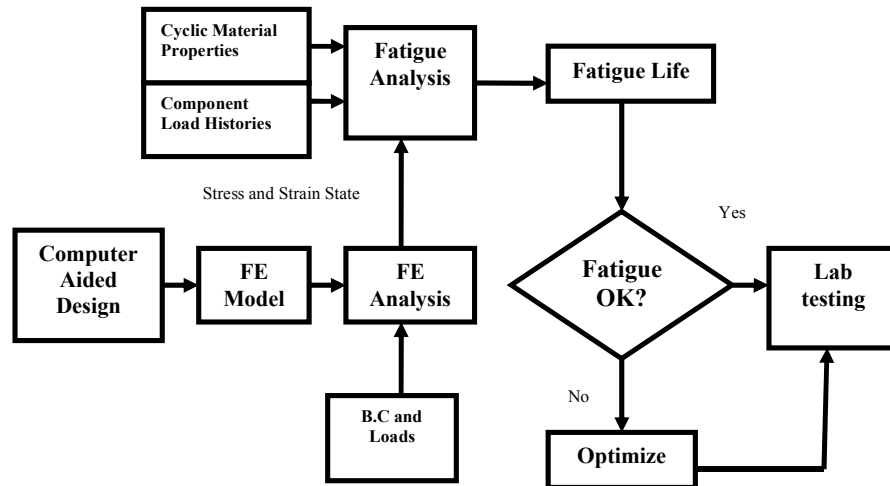


Figure 3.1: Finite element based fatigue life prediction analysis.

3.3 Finite Element based Fatigue Analysis

In this case, two computational processes are utilized to perform the analysis including early structural modeling. The purposes of analyzing the structure model are to reduce cost and other any addition factor that may lead to waste in production. The processes due to analysis are as followed:

- i. Finite element analysis (FEA) – to determine the stress/strain state of a component in a given load condition.
- ii. Fatigue analysis – to calculate the fatigue life for the component of interest and identify the critical locations.

The fatigue life is used to compute the fatigue life of the component. The required inputs for the fatigue analysis are shown in Figure 3.2.